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Sleep disordered breathing and acute mountain sickness in workers rapidly transported to the South Pole (2835 m)

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ABSTRACT

Background: Sleep disordered breathing may be a risk factor for high altitude illness. Past Antarctic sleep studies suggest that rapid transport from sea level (SL) to the Amundsen Scott South Pole Station (SP, 2835 m) increases risk of Acute Mountain Sickness (AMS). We analyzed sleep studies in 38 healthy polar workers to explore the association between sleep disordered breathing and AMS after rapid transport to the South Pole.

Methods: Subjects completed a baseline questionnaire, performed basic physiology tests, and were evaluated for AMS and medication use using an extended Lake Louise Questionnaire (LLQ) during their first week at the South Pole. Participants were included in this study if they took no medications and underwent polysomnography on their first nights at Sea Level and the South Pole using the Vivometrics LifeShirt®. Within group changes were assessed with Wilcoxon signed rank tests and between group differences were assessed with Kruskal–Wallis rank sum tests.

Results: Overall, 21/38 subjects met criteria for AMS at some time on or prior to the third morning at the South Pole. Subjective poor sleep quality was reported by both AMS (65%) and no AMS (41%) groups. The Apnea Hypopnea Index (AHI) increased significantly in both the AMS and no AMS groups, but the difference in the increase between the two groups was not statistically significant. Increased AHI was not associated with increased AMS symptoms. Previous altitude illness ($p = 0.06$) and residence at low altitudes ($p = 0.02$) were risk factors for AMS.

Conclusion: AMS was not significantly associated with sleep architecture changes or increased AHI. However, AHI sharply increased at South Pole (19/38 participants) primarily due to central apneas. Those developing AMS were more likely to have experienced previous problems at altitude and reported living at lowland altitudes within the 3 months prior to rapid transport to the South Pole than those without AMS.

1. Background

Periodic breathing during sleep is a common and unpleasant experience for nearly all high altitude travellers. These realities coupled with the fact that sleep at altitude intensifies hypoxia and the fact that high altitude illnesses are primarily caused by hypoxia have led many to explore the association between sleep patterns and high altitude illnesses such as acute mountain sickness (AMS) high altitude cerebral edema (HACE) and High Altitude Pulmonary Edema (HAPE).

AMS is currently defined as a constellation of symptoms that include headache, nausea or loss of appetite, shortness of breath, sleeping difficulty, and dizziness or lightheadedness (Taylor, 2011). AMS is not a life threatening illness, but it can interrupt work schedules or planned itineraries. Untreated AMS is thought to be a precursor to HACE, which is marked by extreme lethargy, neurological dysfunction, unconsciousness, and eventually death (Bhutia et al., 2013; Basnyat et al., 2000). HAPE often follows the development of AMS symptoms but may occur independently and is fatal without treatment (Dehnert et al., 2003; Benner, 2007).

In general, the role sleep disruption plays in development of AMS symptoms remains unclear. Some have observed that sleep desaturation is associated with increased AMS symptoms at altitude (Burgess et al., 2004). Still others have suggested that at some elevations (3000–3500 m), periodic breathing may actually be protective through stabilizing oxygen saturations, whereas at higher elevations, periodic breathing causes altitude symptoms through total sleep deprivation and mental and physical distress (Kupper

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et al., 2008). More recent studies suggest that self-reported sleep disturbance is poorly correlated with headache (the key diagnostic feature of AMS) in La Paz, Bolivia and on Kilimanjaro (3650 and 5200 m, respectively) and the authors speculate that sleep disturbance may represent a pathologic process separate from headache and question the inclusion of sleep criteria in the diagnosis of AMS (Hall et al., 2014).

Each year, more than 300 United States Antarctic Program Personnel are passively transported from McMurdo Station (SL), to the Amundsen-Scott South Pole station (SP, 500–520 mmHg, 2835 m) in about 3 h. Once at elevation, sleep problems have been shown to persist for several days peaking on day 1 and 2 (Anderson et al., 2011). One previous Antarctic study on sleep and AMS focused on only two male subjects at the South Pole and found a 100% increase in stage one sleep and 50% decrease in REM sleep, with the subsequent development of AMS in one of the subjects (Joern et al., 1970). In addition to sleep problems, the incidence of AMS at the South Pole is higher than at comparable geographical altitudes (Anderson et al., 2011). Given that AMS levels are high and that a majority of people report poor sleep quality on arrival at the South Pole station; we collected sleep data and altitude symptom data in 38 healthy non-acclimatized subjects not taking altitude medications in order to explore the associations between sleep and acute mountain sickness at the South Pole.

This study expands on previous extreme environmental medical research in Antarctica and explores a question from a small hypothesis generating study during the early years of USAP. This relatively large sleep study also adds to high altitude research that explores the role of sleep in the development of AMS. Other Antarctic sleep studies address long-term changes in circadian rhythm, mood, and sleep architecture, but AMS symptoms and their relationship to sleep physiology after rapid transport have not been studied at the South Pole since 1970 (Bhattacharyya et al., 2008; Shurley et al., 1970; Yoneyama et al., 1999).

2. Methods

Subjects enrolled after arriving at McMurdo Station in Antarctica during the summer seasons of 2006–2007 and 2007–2008. The study was approved by the IRB at the Mayo Clinic in Rochester, Minnesota and all subjects gave written informed consent after reading the study protocol.

All participants had received a careful physical and mental health screening prior to deployment and were recruited if they were planning to stay at the South Pole for more than 1 week. Medication usage was carefully documented. Antarctic medical staff gave subjects a briefing on altitude illness before the flight to the South Pole and participants were given packets of acetazolamide along with instructions for use.

All subjects completed a baseline informational survey and underwent baseline physiology testing to document height, weight, heart rate, pulse-oximetry, breath-hold time and with oximetry, body fat measurement, and blood pressure. Height was documented using a single wall chart at baseline only, and weight was documented using a Tanita digital scale Model 682-BF (Tanita Corporation of America, Inc. (Arlington Heights, IL). HR and Oximetry data were collected using a Nonin 2500 PalmSAT Pulse Oximeter (Plymouth, MN). Body fat measurements were collected using Lange Skinfold calipers. Females were tested using the triceps, suprailiac, and abdominal skinfolds and males were tested using the chest, triceps, and subscapular skinfolds. Blood pressure was tested manually with a stethoscope and sphygmomanometer.

The baseline questionnaire recorded demographic information, recent travel, elevation of permanent residence, previous problems at altitude, and recent exposure to high altitude. Other information was also recorded such as medication use, self-reported activity levels, job description, and current illness or injury.

A total of 70 subjects underwent sleep studies at both Sea Level and the South Pole during the 2-year study. Three subjects were excluded from analysis due to missing baseline questionnaire data, one was excluded due to symptoms at Sea Level consistent with AMS, two were excluded for missing medication data, and 26 were excluded because they reported taking acetazolamide during the first day at the South Pole. The final analysis included the 38 subjects with complete study results who reported taking no acetazolamide during the first day at the South Pole.

Subjects were asked to complete Lake Louise Questionnaires (LLQ) during their flight to the South Pole and each morning for 7 days after arrival. Medication use and symptoms were recorded. The standard Lake Louise scoring mechanism was used to document AMS, which requires the presence of a headache and a Lake Louise Symptom Score ≥ 3. For this study, subjects were grouped as 'ever AMS' if they reported symptoms consistent with AMS on the questionnaires filled out during the flight to the South Pole or at day 1, day 2, or day 3 at the South Pole.

The LifeShirt (Vivometrics, Inc., Ventura, CA) is a non-invasive multi-sensor continuous monitoring system that collects body data including: sleep profiles, body position, respiratory patterns, heart rate, and oxygen saturation. The LifeShirt vest is an easy to wear, machine washable garment where sensors are woven into the shirt around the subject's chest and abdomen. Adhesive electrodes are placed appropriately for electrocardiogram and sleep monitoring. A handheld monitor encrypts and stores all of the physiological data to a compact flash memory card. Vivo logic software (version 3.0) provides data processing and reports used for statistical analysis.

2.1. Statistical methods

Data were summarized as count (percentage), median (interquartile range), or mean $\pm$ SD. Differences in non-ordered categorical variables between groups were assessed with a chi-square test or Fisher's exact test. Differences in ordered categorical variables and continuous variables between groups were assessed with a Kruskal–Wallis rank sum test. Paired differences from Sea Level to the South Pole were assessed within groups with a Wilcoxon signed rank test. A p-value of 0.05 was considered significant. All analysis was performed using SAS version 9.4 (SAS Institute Inc., Cary, NC).

3. Results

Twenty-one of 38 individuals met criteria for AMS at some time between the flight to the South Pole and the 3rd morning at the South Pole. There were no significant differences in baseline characteristics with regards to age, sex, BMI, and body fat percentage for those with AMS compared to those without AMS. Subjects with AMS reported residing at lower elevations during the 3 months prior to the study compared to those without AMS ($p = 0.02$). Subjects with AMS also tended to report more previous problems at altitude compared to those without AMS ($p = 0.06$). Please see Table 1 for further baseline data.

Difficulty sleeping was experienced in both groups with 65% in the AMS group that slept worse than usual and 41% in the no AMS group as reported on day 3 at the South Pole. One individual was unable to sleep at all in each group. Subjects with AMS reported worse general health symptoms than the no AMS group but other health symptoms were not significantly different between the groups (Table 2).

Time spent in various sleep stages (awake, light non-REM, deep non-REM, REM) did not significantly change between Sea Level and

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Table 1
General characteristics among subjects with AMS vs. without AMS.

Baseline characteristic	No AMS ($n=17$)	AMS* ($n=21$)	$p^{\dagger}$
Age, years, median (Q1, Q3)	30 (25, 35)	34 (30, 37)	0.24
Male gender, No. (%)	13 (76%)	13 (62%)	0.34
Height, cm, Median (Q1, Q3)	177.8 (175.3, 181.6)	171.5 (168.9, 180.3)	0.21
Weight, kg, Median (Q1, Q3)	79.5 (74.5, 84.1)	73.2 (67.0, 86.5)	0.09
BMI, kg/m2, Median (Q1, Q3)	25.8 (24.1, 27.4)	24.6 (23.1, 26.4)	0.16
Body fat, %, Median (Q1, Q3)	15.5 (11.5, 21.1)	19.9 (13.8, 22.1)	0.36
Elevation of Residence (last 3 months), No. (%)			0.023
<5000 ft	8 (47%)	17 (81%)	
5000–7500 ft	7 (41%)	4 (19%)	
7500–10,000 ft	2 (12%)	0 (0%)	
Previous altitude experience, No. (%)			0.06
No previous exposure	2 (12%)	0 (0%)	
No previous problems	9 (53%)	7 (33%)	
Previous problems	6 (35%)	14 (67%)	
Previous South Pole experience, No. (%)			0.62
No previous exposure	9 (53%)	9 (43%)	
No previous problems	2 (12%)	5 (24%)	
Previous problems	6 (35%)	7 (33%)	
Sleep score, No. (%)			0.93
0	12 (75%)	16 (76%)	
1	4 (25%)	3 (14%)	
2	0 (0%)	2 (10%)	
Type of work at South Pole, No. (%)			0.90
Low Intensity Work	11 (65%)	14 (67%)	
Moderate intensity work	6 (35%)	7 (33%)	

* Subjects were grouped as 'AMS' if they were diagnosed with acute mountain sickness any time between the flight to the South Pole through the 3rd morning at the South Pole.
† p-values are from Kruskal–Wallis rank sum tests.

the South Pole for either AMS or no AMS groups. Sleep efficiency (TST/SPT) also did not significantly change from Sea Level to the South Pole in either group (Table 3).

Compared to SL, mean nighttime SaO_2% decreased in both AMS (12%, $p<0.001$) and no AMS (14%, $p<0.001$) during sleep at the South Pole. Both groups also experienced an increase in the number of oxygen desaturation events/hour where levels fell more than 3% below mean nighttime SaO_2% (oxygen desaturation index = ODI > 3%). However the change in SaO_2% and oxygen desaturation events from Sea Level to the South Pole did not significantly differ between groups. Breathing rate increased by a median of 1.7 breaths per minute in both groups ($p<0.001$). Nighttime minute ventilation also increased in both groups (AMS 2.2 L/min, $p<0.001$; no AMS 1.8 L/min, $p=0.008$) along with Vt/Ti, a measure of inspiratory effort, (AMS 91, $p<0.001$; no AMS 51, $p=0.03$). Nighttime values for heart rate increased by a median of 10 beats per minute (bpm) in both the AMS and no AMS groups ($p<0.001$). The R to R interval decreased for both AMS (0.11 s, $p=0.003$) and no AMS groups (0.12 s, $p=0.005$). None of the changes in breathing or heart rate were significantly different between groups (Table 3).

At Sea Level, sleep was normal in this group and there was only one individual in the AMS group that experienced an AHI > 15 events per hour. During sleep at altitude both groups experienced significant increases in the number of apneas (median increase for AMS 26, $p<0.001$; no AMS 11, $p<0.001$) and hypopnea events per hour (median increase for AMS 8, $p<0.001$; no AMS 4, $p<0.001$) (apnea hypopnea index = AHI) over baseline (Table 4) but the changes in AHI were not statistically significant between groups. An AHI > 15 events per hour is considered disordered breathing. At SP, 19 (50%) of subjects experienced disordered breathing with the majority of these events scored as central apneas or hypopneas with very few mixed or obstructive events.

In both groups, median values for seated HR increased (AMS 6 bpm, $p<0.001$; no AMS 9 bpm, $p=0.03$), resting SaO_2% decreased (AMS 7%, $p<0.001$; no AMS 9%, $p<0.001$), breath hold times decreased (9 s in both groups, $p<0.001$), and SaO_2% at the end of breath hold times decreased (AMS 7%, $p<0.001$; no AMS 12%, $p<0.001$) from Sea Level to the South Pole (Table 5). Only the decrease in resting SaO_2% was nominally significantly different between the AMS and no AMS groups (7% vs. 9%, $p=0.05$). Median resting systolic and diastolic blood pressures did not significantly change from Sea Level to the South Pole in either group.

During orthostatic challenge at SP, median heart rate increased from 80 to 96 bpm ($p<0.001$) in the AMS group and from 90 to 102 bpm ($p<0.001$) in the no AMS group when standing from a seated position. Median systolic blood pressure did not significantly change in either group but diastolic blood pressure increased in AMS (66–76 mmHg, $p<0.001$) and no AMS (70–80 mmHg, $p<0.001$) at the South Pole when standing from a seated position. These changes during the orthostatic challenge at the South Pole were not significantly different between AMS and no AMS (Table 5).

4. Discussion

Overall, 55% of subjects met criteria for AMS ($n=21$) at some point during their first 3 days at the South Pole. As we would expect, more subjects in the no AMS group had resided at altitudes > 5000 ft in the 3 months prior to arrival than the AMS group. Those in the no AMS group also had fewer previous problems with illness at altitude.

Both groups also confirmed what we know about physiologic derangements during sleep at altitude. Both AMS and no AMS groups experienced sharp decreases in nighttime SaO_2% and a significant increase in the AHI and the ODI > 3% during the first night of sleep at the South Pole. Most of the increase in AHI and ODI > 3% was from central apneas or hypopneas rather than mixed events or obstructive events. While differences between AMS and no AMS groups did not achieve statistical significance, the trend revealed in Table 4 shows obvious increases in apnea–hypopnea events for both groups. Since disordered breathing at altitude was experienced by both groups our study may lend support to the idea that poor sleep and disordered breathing represent a separate process from AMS (Hall et al., 2014). The poor correlation of LLQ criteria

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Table 2
Symptoms on day 3, no AMS and AMS groups.

Day 3 characteristic	No AMS ($n=17$)	AMS* ($n=21$)	$p^{\dagger}$
Headache			0.004
None	17 (100%)	12 (60%)	
Mild headache	0 (0%)	5 (25%)	
Moderate headache	0 (0%)	3 (15%)	
GI Symptoms			0.19
None	17 (100%)	18 (90%)	
Poor appetite or nausea	0 (0%)	2 (10%)	
Fatigue/weakness			0.43
None	12 (71%)	11 (55%)	
Mild fatigue or weakness	4 (24%)	9 (45%)	
Moderate fatigue or weakness	1 (6%)	0 (0%)	
Dizzy/lightheaded			0.50
None	15 (88%)	16 (80%)	
Mild dizziness	2 (12%)	4 (20%)	
Difficulty sleeping			0.15
None	10 (59%)	7 (35%)	
Did not sleep as well as usual	5 (29%)	8 (40%)	
Woke many times, poor night's sleep	1 (6%)	4 (20%)	
Could not sleep at all	1 (6%)	1 (5%)	
Shortness of breath at rest			0.36
None	17 (100%)	19 (95%)	
Mildly short of breath	0 (0%)	1 (5%)	
Shortness of breath with activity			0.38
None	6 (35%)	4 (20%)	
Mildly short of breath	10 (59%)	15 (75%)	
Moderately short of breath	1 (6%)	1 (5%)	
Edema/swelling			0.46
None	15 (88%)	19 (95%)	
Swelling on one spot	2 (12%)	1 (5%)	
Mental status symptoms			0.19
None	17 (100%)	18 (90%)	
Little slow in thinking	0 (0%)	2 (10%)	
Cough symptoms			0.87
None	15 (88%)	18 (90%)	
More than usual	2 (12%)	2 (10%)	
General health symptoms			0.015
None	17 (100%)	14 (70%)	
A little ill but can do anything	0 (0%)	5 (25%)	
Somewhat ill and limited	0 (0%)	1 (5%)	

* Subjects were grouped as 'AMS' if they were diagnosed with acute mountain sickness any time between the flight to the South Pole through the 3rd morning at the South Pole.
† p-Values are from Kruskal–Wallis rank sum tests.

Table 3
Polysomnography results for no AMS ($n=17$) and AMS ($n=21$) at Sea Level and South Pole and overall median change.

Sleep variable	No AMS ($n=17$)			AMS* ($n=21$)			Change (SP-SL)		
	Sea Level Median (IQR)	South Pole Median (IQR)	$p^{\dagger}$	Sea Level Median (IQR)	South Pole Median (IQR)	$p^{\dagger}$	No AMS ($n=17$) Median (IQR)	AMS* ($n=21$) Median (IQR)	$p^{\dagger}$
Heart rate (beats/min)	64.5 (61.3, 70.5)	76.3 (73.0, 83.1)	<.001	59.5 (57.6, 67.7)	74.6 (65.7, 80.8)	<.001	10.0 (7.8, 15.3)	9.9 (7.8, 13.8)	0.94
Breaths per minute	17.3 (15.7, 18.2)	18.0 (17.6, 19.4)	<.001	16.5 (15.3, 17.5)	17.5 (16.6, 19.4)	<.001	1.7 (0.99, 2.41)	1.7 (0.53, 2.13)	0.78
R to R interval	0.94 (0.89, 1.01)	0.81 (0.73, 0.85)	0.005	1.0 (0.90, 1.08)	0.84 (0.78, 0.95)	0.003	−0.12 (−0.19, −0.09)	−0.11 (−0.21, −0.09)	0.77
% Time awake	18.2 ± 7.5	31.0 ± 35.0	0.45	16.0 ± 6.2	23.0 ± 21.1	0.39	13.3 ± 31.4	7.5 ± 22.0	0.91
% Time light non-REM	51.2 ± 11.1	43.8 ± 22.2	0.36	53.6 ± 7.0	51.7 ± 17.2	0.77	−7.6 ± 23.8	−2.5 ± 15.7	0.80
% Time deep non-REM	10.0 ± 3.7	9.8 ± 6.8	0.73	12.8 ± 5.2	10.9 ± 6.0	0.18	0.1 ± 5.5	−1.8 ± 4.9	0.28
% Time REM	20.6 ± 14.8	15.5 ± 9.8	0.37	17.6 ± 4.0	14.4 ± 6.6	0.19	−5.8 ± 17.7	−3.2 ± 8.7	0.97
Sleep efficiency (TST/SPT) (%)	94.2 (90.9, 96.7)	94.9 (84.8, 98.3)	0.56	95.6 (93.0, 96.8)	95.7 (88.1, 97.8)	0.56	0.50 (−11.5, 3.9)	1.7 (−6.3, 3.1)	0.93
Oximetry									
Mean SaO_2 (%)	94.7 (92.4, 95.6)	80.9 (78.8, 83.2)	<.001	94.5 (93.7, 95.6)	81.7 (78.0, 84.1)	<.001	−13.8 (−15.5, −8.8)	−12.2 (−14.8, −10.8)	0.71
ODI > 3% (events/h)	1.3 (0.60, 3.10)	15.2 (6.5, 30.5)	<.001	1.6 (0.50, 3.30)	12.2 (7.9, 32.5)	<.001	7.8 (4.0, 29.2)	9.9 (5.4, 31.4)	0.53
Sleep respiration									
Minute ventilation	9.4 (7.9, 10.8)	11.1 (8.8, 13.2)	0.008	8.9 (7.8, 10.6)	10.4 (9.0, 12.9)	<.001	1.8 (0.68, 3.29)	2.2 (1.0, 3.1)	0.62
qDEEL	116 (100, 137)	130 (88, 182)	0.08	100 (76, 141)	115 (84, 177)	0.002	8.6 (−6.3, 39.9)	16.5 (3.7, 43.6)	0.67
F/Vt	41.0 (35.9, 43.8)	41.7 (36.5, 46.2)	0.25	40.2 (32.2, 46.7)	39.1 (35.2, 48.1)	0.67	2.0 (−2.0, 7.7)	0.93 (−5.8, 4.4)	0.46
Vt/Ti	367 (335, 403)	420 (341, 497)	0.029	345 (313, 414)	403 (370, 523)	<.001	50.6 (9.9, 115.1)	90.5 (34.3, 119.2)	0.41

* Subjects were grouped as 'AMS' if they were diagnosed with acute mountain sickness any time between the flight to the South Pole through the 3rd morning at the South Pole.
† p-Values for paired tests (Sea Level vs. South Pole) within groups are from Wilcoxon signed rank tests and p-values for comparison of change between the two groups are from Kruskal–Wallis rank sum tests.

found between headache and sleep disturbance has been described before (Macinnis et al., 2013).

Unlike the findings from Joern et al. (1970) sleep architecture did not significantly change in either the AMS or no AMS groups on the first night at altitude. The percent time in wake, LNREM (light non-REM), DNREM (deep non-REM), and REM phases of sleep were relatively unchanged following rapid ascent. The percent time in REM sleep was not associated with AMS status or decreased mean nighttime SaO_2% as in the previous case report from Joern et al. (1970).

While our cohort is relatively large for a field based sleep study, the small sample makes it difficult to achieve statistical significance for what may be very subtle physiological derangements caused by poor sleep. Our study is also limited in that workers were studied on only their first night between two locations, and that many do not sleep well in new surroundings. Arterial blood gases were not taken to best evaluate oxygen saturations. To improve upon this study, lengthening the duration of sleep and AMS symptom monitoring to 7 days would increase the opportunity of detecting differences between the AMS and No AMS groups. Workers arrived at the

Table 4
Sleep disruption during polysomnography for no AMS and AMS groups with change from Sea Level to South Pole.

AHI variable	No AMS ($n=17$)			AMS* ($n=21$)			Change (SP-SL)		
	Sea Level Median (IQR) or N (%)	South Pole Median (IQR) or N (%)	$p^{\dagger}$	Sea Level Median (IQR) or N (%)	South Pole Median (IQR) or N (%)	$p^{\dagger}$	No AMS ($n=17$) Median (IQR)	AMS* ($n=21$) Median (IQR)	$p^{\dagger}$
Overall	0.40 (0.20, 1.70)	11.8 (3.4, 41.7)	<.001	0.60 (0.20, 3.90)	31.0 (3.6, 45.8)	<.001	11.2 (2.5, 40.3)	26.0 (3.2, 42.6)	0.61
≤15	17 (100.0)	10 (58.8)		20 (95.2)	9 (42.9)				
>15	0 (0.0)	7 (41.2)		1 (4.8)	12 (57.1)				
Central	0.00 (0.00, 0.10)	1.0 (0.20, 17.00)	<.001	0.10 (0.00, 0.20)	1.7 (0.40, 15.80)	<.001	0.70 (0.20, 16.90)	1.6 (0.30, 15.70)	0.76
≤15	17 (100.0)	12 (70.6)		21 (100.0)	13 (61.9)				
>15	0 (0.0)	5 (29.4)		0 (0.0)	8 (38.1)				
Mixed	0.00 (0.00, 0.10)	1.0 (0.20, 4.00)	<.001	0.00 (0.00, 0.20)	1.8 (0.20, 6.80)	<.001	1.0 (0.00, 4.00)	1.2 (0.20, 6.80)	0.69
≤15	17 (100.0)	15 (88.2)		21 (100.0)	21 (100.0)				
>15	0 (0.0)	2 (11.8)		0 (0.0)	0 (0.0)				
Obstructive	0.00 (0.00, 0.30)	0.30 (0.00, 2.40)	0.026	0.10 (0.00, 0.50)	0.90 (0.20, 1.70)	0.003	0.30 (0.00, 2.40)	0.60 (0.10, 1.70)	0.99
≤15	17 (100.0)	17 (100.0)		21 (100.0)	21 (100.0)				
Hypopneas	0.20 (0.10, 0.70)	4.0 (1.3, 14.0)	<.001	0.50 (0.10, 3.00)	11.4 (2.8, 18.9)	<.001	3.8 (1.3, 13.7)	8.2 (2.6, 11.6)	0.39
≤15	17 (100.0)	14 (82.4)		21 (100.0)	13 (61.9)				
>15	0 (0.0)	3 (17.6)		0 (0.0)	8 (38.1)				

* Subjects were grouped as 'AMS' if they were diagnosed with acute mountain sickness any time between the flight to the South Pole through the 3rd morning at the South Pole.
† p-Values for paired tests (Sea Level vs. South Pole) within groups are from Wilcoxon signed rank tests and p-values for comparison of change between the two groups are from Kruskal–Wallis rank sum tests.

Table 5
Physiology test results for no AMS ($n=17$) and AMS ($n=21$) groups at Sea Level and South Pole.

Characteristic	No AMS ($n=17$)			AMS* ($n=21$)			Change (SL-SP)		
	Sea Level Median (IQR)	South Pole Median (IQR)	$p^{\dagger}$	Sea Level Median (IQR)	South Pole Median (IQR)	$p^{\dagger}$	No AMS Median (IQR)	AMS* Median (IQR)	$p^{\dagger}$
Rest seated HR	75 (72, 84)	90 (77, 94)	0.026	71 (60, 80)	80 (68, 90)	<0.001	9 (−2, 21)	6 (2, 10)	0.74
Rest seated SBP	112 (98, 118)	112 (102, 118)	0.77	108 (100, 118)	106 (98, 112)	0.37	0 (−12, 20)	0 (−14, 6)	0.42
Rest seated DBP	68 (64, 72)	70 (65, 74)	0.63	70 (64, 78)	66 (62, 72)	0.26	2 (−9, 10)	−2 (−14, 8)	0.30
Rest O2 saturation	98 (97, 99)	89 (86, 90)	<0.001	98 (97, 98)	90 (89, 92)	<0.001	−9 (−11, −8)	−7 (−9, −6)	0.05
Breath hold time	24 (19, 45)	14 (12, 19)	<0.001	24 (21, 28)	17 (14, 19)	<0.001	−9 (−13, −6)	−9 (−13, −4)	0.50
O2 saturation at end of breath hold	94 (91, 96)	83 (80, 85)	<0.001	95 (94, 98)	86 (81, 90)	<0.001	−12 (−14, −8)	−7 (−12, −6)	0.12
Rest standing HR (peak)	97 (91, 101)	102 (95, 112)	0.016	92 (81, 101)	96 (91, 105)	0.043	8 (1, 19)	6 (−2, 16)	0.32
Rest standing SBP (30 s)	114 (103, 120)	110 (102, 122)	0.40	104 (98, 116)	110 (96, 116)	0.64	4 (−4, 8)	0 (−10, 10)	0.48
Rest standing DBP (30 s)	74 (70, 78)	80 (74, 82)	0.22	72 (60, 82)	76 (66, 79)	0.60	6 (0, 12)	−1 (−6, 14)	0.64
Rest standing 02 saturation (30 s)	97 (96, 98)	90 (88, 92)	<0.001	98 (97, 98)	90 (89, 92)	<0.001	−7 (−9, −5)	−7 (−9, −6)	0.99

* Subjects were grouped as 'AMS' if they were diagnosed with acute mountain sickness any time between the flight to the South Pole through the 3rd morning at the South Pole.
† p-Values for paired tests (Sea Level vs. South Pole) within groups are from Wilcoxon signed rank tests and p-values for comparison of change between the two groups are from Kruskal–Wallis rank sum tests.

station on a few different nights with varying weather dependent barometric pressures, unequal numbers of male and female subjects met our inclusion criteria, and we could not control for previous elevation of previous residence.

5. Conclusion

The majority of our subjects (55%) experienced AMS symptoms during the first 3 days at altitude (including poor sleep quality) and we observed marked oxygen desaturation and apnea–hypopnea events during their first night of sleep at the South Pole. More individuals in the AMS group (65%) reported poor sleep quality than in the no AMS group (41%). Nonetheless, our data do not reveal a statistically significant association between sleep disordered breathing and AMS. Other factors including previous problems with altitude illness and recent residence at higher altitude remained strongly associated with AMS in this group of polar workers.

References

Anderson, P.J., Miller, A.D., O'Malley, K.A., Ceridon, M.L., Beck, K.C., Wood, C.M., Wiste, H.J., Mueller, J.J., Johnson, J.B., Johnson, B.D., 2011. Incidence and symptoms of high altitude illness in South Pole workers: Antarctic Study of Altitude Physiology (ASAP). Clinical medicine insights. Circ. Respir. Pulm. Med. [electronic resource] 5, 27–35.

Basnyat, B., Subedi, D., Sleggs, J., Lemaster, J., Bhasyal, G., Aryal, B., Subedi, N., 2000. Disoriented and ataxic pilgrims: an epidemiological study of acute mountain sickness and high-altitude cerebral edema at a sacred lake at 4300 m in the Nepal Himalayas. Wilderness Environ. Med. 11, 89–93.

Benner, D.C., 2007. High-altitude illnesses: from the limited to the potentially lethal. JAAPA 20, 37–41.

Bhattacharyya, M., Pal, M.S., Sharma, Y.K., Majumdar, D., 2008. Changes in sleep patterns during prolonged stays in Antarctica. Int. J. Biometeorol. 52, 869–879.

Bhutia, M., Goyal, K., Rai, A., Kedia, S., Kumar, N., Mitra, R., 2013. High altitude cerebral edema with a fatal outcome within 24 h of its onset: Shall acclimatization be made compulsory? Saudi J. Anaesth. 7, 488–489.

Burgess, K.R., Johnson, P., Edwards, N., Cooper, J., 2004. Acute mountain sickness is associated with sleep desaturation at high altitude. Respirology 9, 485–492.

Dehnert, C., Schneider, M., Mairbaurl, H., Bartsch, P., 2003. [Acute mountain sickness and high-altitude pulmonary edema How to protect the mountain climber from the effects of the altitude haze]. MMW Fortschr. Med. 145, 33–35.

Hall, D.P., Maccormick, I.J., Phythian-Adams, A.T., Rzechorzek, N.M., Hope-Jones, D., Cosens, S., Jackson, S., Bates, M.G., Collier, D.J., Hume, D.A., Freeman, T., Thompson, A.A., Baillie, J.K., 2014. Network analysis reveals distinct clinical syndromes underlying acute mountain sickness. PLOS ONE 9, e81229.

Joern, A.T., Shurley, J.T., Brooks, R.E., Guenter, C.A., Pierce, C.M., 1970. Short-term changes in sleep patterns on arrival at the South Polar Plateau. Arch. Inter. Med. 125, 649–654.

Kupper, T., Schoffl, V., Netzer, N., 2008. Cheyne stokes breathing at high altitude: a helpful response or a troublemaker? Sleep Breath. 12, 123–127.

Macinnis, M.J., Lanting, S.C., Rupert, J.L., Koehle, M.S., 2013. Is poor sleep quality at high altitude separate from acute mountain sickness? Factor structure and internal consistency of the Lake Louise Score Questionnaire. High Alt. Med. Biol. 14, 334–337.

Shurley, J.T., Pierce, C.M., Natani, K., Brooks, R.E., 1970. Sleep and activity patterns at South Pole station. A preliminary report. Arch. Gen. Psychiatry 22, 385–389.

Taylor, A.T., 2011. High-altitude illnesses: physiology, risk factors, prevention, and treatment. Rambam Maimonides Med. J. 2, e0022.

Yoneyama, S., Hashimoto, S., Honma, K., 1999. Seasonal changes of human circadian rhythms in Antarctica. Am. J. Physiol. 277, R1091–R1097.

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